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(57) Abstract

A method of reducing features occurring at particular frequencies such as at coincidence is described. A panel (11) has exciters (13, 15) arranged to reduce the feature. The exciters may be driven in phase but be spaced apart by a distance substantially equal to half the wavelength of bending waves in the panel at this particular frequency.

(57) Abrégé

L'invention concerne un procédé permettant de réduire les phénomènes intervenant à des fréquences particulières comme les coïncidences. Un panneau (11) comprend des excitateurs (13, 15), disposés pour réduire le phénomène, qui peuvent être attaqués en phase mais qui sont espacés d'une distance sensiblement égale à la moitié de la longueur d'onde des ondes de flexion dans le panneau à la fréquence particulière considérée.

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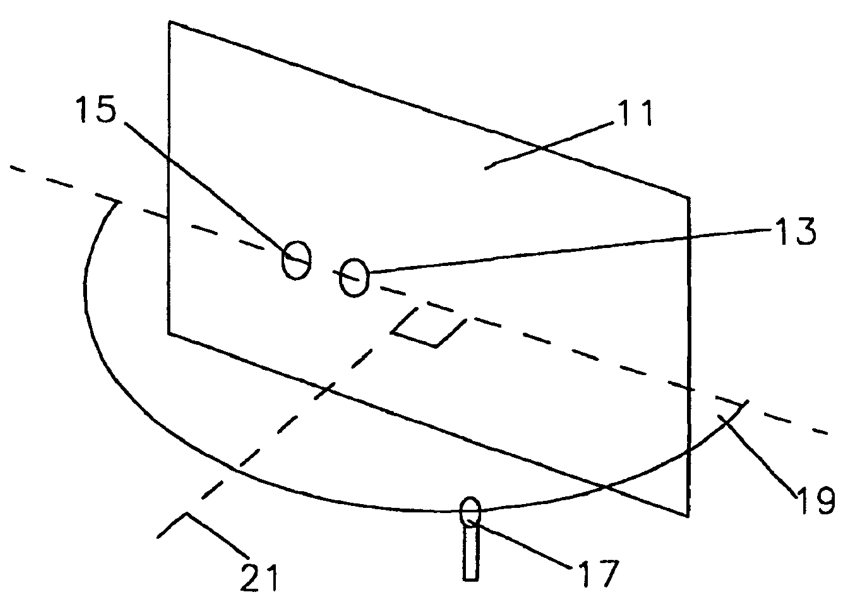

(57) Abstract

A method of reducing features occurring at particular frequencies such as at coincidence is described. A panel (11) has exciters (13, 15) arranged to reduce the feature. The exciters may be driven in phase but be spaced apart by a distance substantially equal to half the wavelength of bending waves in the panel at this particular frequency.

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Description

TITLE: ACOUSTIC DEVICES

DESCRIPTION

FIELD OF INVENTION

This invention relates to acoustic devices including a panel-form member relying on bending wave action with a distribution of resonant modes of surface vibration for acoustic operation, and has arisen specifically in relation to panel-form loudspeakers.

BACKGROUND TO INVENTION

As taught in various patent applications in the name of New Transducers Limited, starting with published International Application W097/09842, panel-form loudspeakers are amenable to optimisation as to geometries and bending stiffnesses of the panels concerned, and as to locations of excitation exciters of and for those panels.

Even as so optimised, circumstances can arise where, in operation, some frequencies are candidates for variation of their contributions, e.g. troublesome in some way such that reduction, even substantial suppression, of their contributions would be useful. Indeed, one particular example concerns coincidence frequencies that, at least in large panels, result in directional radiation at extreme angles to the panel surface and produce irregularities beyond dimensionally related smoothing effects inherently useful in smaller panels.

SUMMARY OF INVENTION

According to a first aspect of the invention there is provided a bending wave loudspeaker comprising

a panel capable of supporting bending waves;

a first exciter mounted on the panel for exciting bending waves in the panels to produce an acoustic output, wherein the acoustic output response of the panel driven by said first exciter has an feature at a known frequency; and

a second exciter mounted on the panel for exciting bending waves in the panel to produce an acoustic output, wherein the second exciter is arranged such that when the first and second exciters are commonly driven the feature is smoothed.

The second exciter may be arranged at a predetermined distance from the first exciter to smooth the feature. The relative phase and gain of the first and second exciters may be controlled; the second exciter may have a filter,

attenuator, delay, phase control, signal processing and/or a variable gain control in association with it. Since, in general, it is the relative amplitude and phase of the signals provided to the two exciters that matters, alternatively or additionally a filter, attenuator, delay, phase control, signal processing or variable gain control may be provided in association with the first exciter. The second exciter may be connected in phase or in anti-phase with the first exciter. A combination of any or all these methods may be used.

The feature may be a peak, prominence or elevation in the acoustic output (sound pressure level) as a function of frequency for constant excitation voltage. The loudspeaker according to the invention may accordingly have an improved frequency response in that the feature is smoothed.

Preferably, the second exciter is arranged spaced away from the first exciter on the panel at a distance substantially equal to one half the wave length of bending waves in the panel at the known frequency.

It may also be possible to use odd multiples of half a wavelength, i.e. one and a half wavelengths, two and a half etc.

The first and second exciters are preferably connected in phase between common terminals. This is readily done by connecting like exciters the same way round in a series or parallel arrangement; bending waves may then be emitted in phase. Of course, when the exciters are half a wavelength apart at a particular frequency the phase relation at that

frequency will cause a desired degree of cancellation to give control and/or smoothing.

If the second exciter were simply to be driven in anti-phase with respect to the first exciter without regard to the placement of the second exciter, then the first and second exciters would tend to produce destructive interference over a broad frequency range resulting in low output, especially at low frequencies. In contrast, by placing the first and second exciters at a distance of one half wave length apart, the first and second exciters may be driven in phase to enhance the acoustic output. Only at the known frequency will the bending waves excited by the two exciters be in anti-phase and hence cancel. Accordingly, the loudspeaker according to the invention can have an improved response at the particular known frequency.

Preferably, the known frequency is the coincidence frequency. At the coincidence frequency, the acoustic properties of the panel change in a non-smooth way. Accordingly, there is often a peak or elevation in the acoustic response at this frequency. This may be smoothed in the loudspeaker according to the invention.

The panel may be anisotropic, and have different coincidence frequencies associated with first and second axes. The second exciter may be spaced away from the first exciter along the first axis to smooth the coincidence frequency feature associated with the bending waves along the first axis, and a third exciter may be provided spaced

away from the first exciter along the second axis at a distance substantially equal to one half the wave length of the bending waves at the coincidence frequency associated with the second axis.

A fourth exciter may be provided; the first, second, third and fourth exciters may define a rectangle on the surface of the panel. Further exciters may be added as required, for example to provide sufficient output power.

The exciters may be separate transducers; for example, each exciter may comprise a voice coil fixed to the panel and a magnet assembly arranged for motion relative to the voice coil. The exciter may be inertial, i.e. the magnet assembly need not be fixed to a separate frame, but the force on the panel may react against the inertia of the magnet assembly. If the exciters are driven in phase, some of the parts may be common. For example, the first and second exciter may comprise a single transducer having a coil and a magnet assembly, the coil having a first region contacting the panel (the first exciter) and a second region contacting the panel (the second exciter), the two positions being spaced apart by one half wavelength of the bending waves at the known frequency.

Although it is preferred to space the exciters at particular distances apart, this is not always possible. Accordingly, in alternative embodiments the second exciter may be located close to the first exciter and driven in anti-phase. In this case, a bandpass filter may be used so that the second exciter is only driven in a predetermined

frequency range around the known frequency.

In embodiments, a reduced number of exciters may be arranged to operate at high frequencies well above coincidence, for example in order to reduce interference effects at these frequencies. This may be done by arranging filters in association with the exciters already described so that only one of them operates at higher frequencies. Since this may upset the electrical and mechanical symmetry of the first, second, third etc. exciters, as an alternative one or more further, separate, higher frequency exciters may be provided. The provision of only a single higher frequency exciter may be advantageous to reduce acoustic interference effects at higher frequencies.

Where a separate higher frequency exciter or exciters is or are provided the low and high frequencies present in a drive signal may be separated by a cross-over circuit or circuits for feeding the higher frequency exciter with frequencies above the cutoff and the other exciters with frequencies below the cutoff. The detailed design of cross-overs is well known in the loudspeaker art; the cross-over may be as sharp as required. The cross-over should not be confused with the bandpass filter mentioned earlier, although the circuitry for each may be combined if convenient.

According to a second aspect of the invention there is provided a bending wave loudspeaker, comprising

a panel capable of supporting bending waves,

first and second exciters mounted on the panel for exciting bending waves in the panel to produce an acoustic output, wherein

the first and second exciters are spaced apart by a distance of one half wave length at a predetermined frequency, so that when the first and second exciters are commonly driven the acoustic output of the panel is affected at the predetermined frequency.

The first and second exciters may be connected in anti-phase to enhance the acoustic output at the predetermined frequency, or in phase to smooth or reduce the acoustic output at that frequency. An enhanced response at a particular frequency is particularly useful for sirens and other acoustic warning devices, where it is only required to produce output at known frequencies.

For the more normal requirement of a smooth loudspeaker response, the first and second exciters may be connected in phase. In this case, other features described above with reference to the first aspect of the invention may also be used, if convenient.

According to a third aspect of the invention, there is provided a method of suppressing an feature in a frequency response of a bending wave loudspeaker having a panel (11) capable of supporting bending waves, and a first exciter (13) mounted on the panel, including determining a frequency at which the response of the first exciter on the panel has a feature, providing a second exciter (15) on the panel arranged such that when the first and second exciters

(13,15) are commonly driven the feature is smoothed.

The second exciter may be provided on the panel at one half of the wavelength of bending waves in the panel at the known frequency. The step of determining the frequency may determine the coincidence frequency associated with a predetermined direction.

According to a further aspect of this invention, a panel-form loudspeaker relying on bending wave action with beneficial distribution of resonant modes of vibration has control of at least one frequency in accordance with spacing between at least two exciter means as associated with the panel concerned.

Said spacing can be from one said exciter means at an optimised location for excitation of said panel to an additional other said exciter means; and may be directly related to transmission speed of bending waves in said panel for said frequency, specifically corresponding to half-wavelength for reduction up to satisfactory suppression when both of said exciter means receive the same signal on an in phase basis.

It is feasible to supply substantially only said one frequency to said additional exciter means, say via narrow bandpass filtering; and to subject same to delay allowing said spacing to be other than said half-wavelength, but with the substantially same effect. Other or further adjustment capability is available from delay applied to rest of input signal, though desirably not differentially as supplied to plural exciter means normally at optimised

locations.

It is the case that supplying said second, additional exciter means at half wave spacing in anti-phase relation to said one exciter means will have opposite effect, i.e. increasing contribution of said frequency in acoustic output of said panel-form loudspeaker.

Direction of said spacing is also significant. Thus, and as another inventive aspect hereof, bending waves in a particular direction of spacing between two exciter means are affected at a frequency corresponding to said spacing. Two such frequencies can be suitably affected by different spacings in the same direction, typically to each side of exciter means at an optimised location, or in different directions for frequencies as associated with such different directions.

In particular embodiments of this invention, and for said frequency related to one of length or width of a substantially rectangular said panel, said spacing will be in a corresponding said direction, i.e. parallel with one of length or width sides or axes. Indeed, it is practical to deal with a least one each of frequencies related to length and width of such rectangular loudspeaker panel, whether by additional exciter means respectively spaced relative to optimised location for one exciter means or each relative to a different optimised location for exciter means.

Where different optimised locations are used for

exciter means, it can be advantageous/convenient to treat each differently as to association of spaced additional exciter means for purposes hereof, including no such association with one or more of used such optimised locations, even if untypically so; association using one direction of the same spacing thus frequency concerned with from only one up to all of used optimised exciter locations; association using another and opposite spacing in the one direction (thus another related frequency) for at least one of the latter used optimised exciter locations; association using another direction and spacing (thus another frequency concerned) with at least one of used optimised exciter locations also having association with said one direction and spacing; further association with additional exciter means at different directions and spacings from the same optimised location of further additional exciter means at spacings meaningful to purposes hereof.

At least for bandpass-filtered frequencies to be affected, it is, of course, feasible to use other spacings and selectively applied delays to achieve substantially the same effects, even one standardised spacing and different delays.

At least where provisions hereof for more than one frequency concerned are applied together relative to one optimised location for exciter means, it can be useful to apply pass filtering to input signals so that only a

selected band is applied to all of the exciter means at and associated with that one optimised location.

Embodiments of this invention affording reduction up to suppression on a selective frequency basis are seen as having particularly useful application to achieving improved acoustic performance relative to the above-mentioned particular problems concerning coincidence frequencies, as will be specifically described and illustrated. Embodiments of this invention affording reinforcement on a selective frequency basis are seen as having particularly useful application where such as a warning siren is required and/or greater loudness or over-ride for messages etc (then feasibly with operation relative to a selected frequency band).

Where signal components to be affected have directivity in output from loudspeaker panels, embodiments of this invention can be deployed in connection with desired directivity effects, including reducing or emphasising same.

Implementations of this invention at least for selective frequency reduction/suppression and involving spaced exciters operating in phase are seen as having some degree of equivalence to larger area excitation, thus possible use of effectively or actually larger area exciter means, then with compensation for inevitable frequency band effects available by way of smaller area exciter means at other locations along with any appropriate pass filtering.

BRIEF INTRODUCTION TO THE DRAWINGS

Specific embodiments of the invention will now be described, purely by way of example, with reference to the accompanying drawings, in which :

Figure 1 is an schematic view of a loudspeaker according to the invention;

Figure 2 is a plan view of a first embodiment of the invention;

Figure 3 is a side view of the first embodiment;

Figure 4 is a graph of acoustic power output at 80° to the perpendicular axis towards the horizontal, using two exciters spaced apart in the horizontal direction, and for comparison using a single exciter;

Figure 5 is a graph of acoustic power output at 80° to the perpendicular axis towards the vertical axis, using exciters spaced apart in the vertical direction, and for comparison using exciters not so spaced;

Figure 6 shows a crossover arrangement of the first embodiment;

Figure 7 shows an alternative crossover arrangement;

Figure 8 shows a second embodiment having nine exciters;

Figure 9 shows the crossover arrangement in the second embodiment;

Figure 10 shows the electrical impedance of the second embodiment;

Figure 11 shows simulated panel displacement for a one-dimensional sample using two exciters;

Figure 12 shows simulated panel displacement for the sample of Figure 11 driven with only one exciter;

Figure 13 shows the on-axis pressure response of the arrangement of Figure 11;

Figure 14 shows the sound pressure as a function of angle at 541.7 Hz;

Figure 15 shows the sound pressure as a function of angle at 2039 Hz;

Figure 16 shows the sound pressure as a function of angle at 4515 Hz;

Figure 17 shows the sound pressure integrated over all angles;

Figure 18 shows a plan view of a loudspeaker according to the invention;

Figure 19 shows a side view of the loudspeaker shown in Figure 18;

Figure 20 shows measured results for the panel of Figures 18 and 19 driving one exciter;

Figure 21 shows measured results for the panel of Figure 18 and 19 driving two exciters; and

Figure 22 illustrates a further arrangement.

DETAILED DESCRIPTION INCLUDING ILLUSTRATED EMBODIMENTS

Referring to following equations (Eq. 1 and Eq. 2) the dependency of wave speed (v) across a panel surface on

frequency (Eq. 1) results in a coincidence frequency (Eq. 2) at which this wave speed equals that of the speed of sound for the lossless panel. At this coincidence frequency, a polar plot for a large panel, e.g. 1450 mm by 1100 mm, will shows sound pressure level (SPL) peaks occurring at extreme angles to the panel surface. This is more apparent in larger panels for a number of reasons. Optimal bending stiffness (B) is higher for larger areas, so coincidence frequency is lower. Any 'beaming' effects for smaller panels are spread due to a smearing function related to panel dimensions. Also, larger panels experience a reduced smearing effect, hence the peaks become more apparent.

Equation 1

$$v(f,\beta,\mu)=\sqrt{2\pi f}\sqrt[4]{\frac{\beta}{\mu}}$$

where $v(f,\beta,\mu)$ is the wave velocity, dependant on f, the frequency in Hz, β, the bending stiffness of panel material, units Newton metres, and μ, the areal density, kilograms per square metre.

Equation 2

$$f_c(\beta,\mu,v)=\frac{v^2}{2\pi}\sqrt{\frac{\mu}{\beta}}$$

Figure 1 shows a schematic diagram of a loudspeaker according to the invention. A panel 11 has first 13 and

second 15 exciters mounted on its surface. Measurements are taken by moving a microphone 17 around a horizontal path 19 to measure the acoustic power response as a function of angle from the centre line 21 perpendicular to the panel.

The first exciter 13 is arranged at an optimum exciter location for coupling to resonant bending waves in the panel, as taught in other patents and applications in the name New Exciters limited, such as WO97/09842. The second exciter is spaced away from the first with the aim that the response at extreme angles and associated with coincidence frequencies is smoother.

To this end, the centre-to-centre spacing S of the exciters 13,15 is at one-half wavelength of the coincidence frequency of waves along the horizontal axis 35.

Figures 2 and 3 shows a specific embodiment of the idea. A rectangular anisotropic panel 11 measuring 1450mm by 1100mm has a 10mm thick core 25 and 0.106mm thick skins 27 made of epoxy loaded with carbon fibres. The skins are attached to the core with 90gsm (grams per square metre) epoxy film 29 loaded on a cotton carrier. Mountings 23 are provided, to support the panel in use.

In order that the panel could function as a projection screen 534gsm PVC projection material 31 was bonded to the panel with double sided film 33.

The panel had a bending stiffness B of 184Nm along the first, long axis 35, 71Nm along the second short axis 37, and an areal mass density of 1.92kg/m^2.

The coincidence frequency is the frequency at which the wavespeed in the panel matches that in free air, taken to be 344m/s. Using the above parameters and equation 1 the coincidence frequency associated with waves in the x direction can be calculated to be at 1924Hz. One half wavelength at this frequency is 89.583mm, so the second exciter 15 was mounted at 90mm from the first 13 along the long axis.

Although the calculation relates to effectively point-source exciters typical available exciters can be up to about 25mm or more in diameter. This is not necessarily a point source, and some adjustment for optimisation may well be necessary, but can be found readily by trial-and-error. A maximum position tolerance in the 5-10% range, for example of about 5mm is expected to apply.

At and just above the coincidence frequency, i.e. about 2KHz, sound is output at that frequency with a strong maximum at an 80-degree angle to the centre line 21. Figure 4 shows the output at 80° both with and without compensation using the second exciter. The measurements were made at 2m distance using 1V excitation, with and without the second exciter 15.

The upper line in Fig. 4, showing the peak at around 2kHz, shows the output for excitation using only the first exciter. The improvement using both exciters 13,15 is readily apparent in Figure 4 and can be seen in the lower line measured using excitation from both exciters. This

line does not show the coincidence peak.

Using the two exciters 13,15 only corrects the feature with regard to beaming in the horizontal plane (the x-axis 35). Beaming can however also occur in the y-axis 37. Since the panel is anisotropic, the coincidence frequency and wavelength of waves along the y-axis is different. The half-wavelength separation at coincidence is calculated in the same way as above to be 54mm. Accordingly, third and fourth exciters 17,19 are provided spaced 54mm from the first and second exciters 13,15 along the y axis. The four exciters form a rectangle. The reason for the use of the rectangle is that it preserves physical symmetry. This in turn makes the mechanical impedance of the exciters substantially equal and so makes the group easier to drive.

Results showing the improvement using the further pair of exciters are presented in Figure 5. The narrower line with a peak at 3kHz represents the acoustic output at 80° below the horizontal using just the first pair of exciters, and the bold line shows the effect of using all four exciters. As above, the peak at coincidence is substantially reduced.

There is very little coincidence effect on axis, i.e. measured by a microphone along the centre line, in anechoic conditions. However, when the loudspeaker is mounted in a room with echoes a listener may hear sound output at all angles, which can reach the listener after being reflected by walls. The loudspeaker according to the invention

provides improved response, even on axis, in these realistic conditions.

A higher frequency exciter 21 is provided (Figure 2) to operate at high frequencies only. The lower and mid-frequencies, including coincidence, are produced by the first through fourth exciters 13,15,17,19. This frequency range division can reduce undesirable high frequency interference effects caused by multiple driving exciters.

The exciters are preferably driven by a cross-over circuit 20 as shown in Fig. 6. The first through fourth exciters are connected between shared common terminals, namely a drive input point 22, and ground 24. The terminals may be connected to a signal source such as an amplifier. The higher frequency exciter 21 is connected in parallel to an inductor L3 and both are connected in series with a capacitor C3; this may be driven from the common terminals or from separate terminals.

The first through fourth exciters 13,15,17,19 are commonly driven, divided into two parallel pairs in series. This exciter array is connected in series with an inductor L2, resistor R1 and capacitor C2 in parallel, which provide a weak filter for providing additional control of the frequency response. In turn, this weak filter is connected in turn to the input 22 through an inductor L1 and to ground 24 through a capacitor C1, to provide low-pass action.

The components shown have values as follows: L1 0.92mH

(low resistance), L2 5.0mH, 0.4Ω, L3 0.9mH (low resistance), C1 6.8μF, C2 100μF, C3 6.8 μF and R1 30Ω.

An alternative arrangement to drive the four exciters 13, 15, 17, 19 is presented in Figure 7. In this arrangement, two of the first through fourth exciters are bridged by a capacitor 39 which shorts out the high frequencies. In this way, only two exciters are driven at higher frequencies.

Figure 8 shows a variation of the above embodiment having further exciters. The first through the fourth exciters are as in the previous embodiment. In this full system fifth 41 and sixth 43 exciters are provided at good locations for coupling to resonant bending waves in the panel. Seventh 45 and eighth 47 exciters are associated with the fifth and sixth exciters respectively, spaced apart from them along the horizontal axis 35. This is because irregularities due to directionality in the horizontal plane is of much greater significance to listeners than vertical irregularities, and such irregularities can be corrected by horizontal spacing. A ninth exciter 49 is also located spaced away from the fifth exciter in the opposite direction to the seventh exciter at a different spacing along the first axis.

The crossover system associated with the full nine-exciter system is shown in Fig. 9. Its calculated or simulated electrical impedance is shown in Figure 10. The resistance drops to a minimum of 8 ohms at between about

12KHz and 500Hz; this is particularly friendly to input signal amplifiers and will readily afford scope for connecting other systems in parallel with the loudspeaker panel 30, if and as desired, and reduces chances of amplifier overload. The cross-over provision actually allows only the fifth exciter 41 to be active for high frequency acoustic output radiation, and is an effective extension of other improvements to high frequency response.

The full nine-exciter system of Figure 3 has a beneficially optimising effect as to angularity in acoustic output behaviour and extension of low frequency operation. Measured echoic response is shown graphically in Figure 8 on an on-axis basis together with an extreme 80-degree angle basis.

Multiple exciters as used herein offer greater control over directivity, and increase maximum SPL levels and bandwidth. This control is achieved by effectively disabling or causing destructive superposition in relation to selected bending waves in a panel, the frequency region affected being controlled by specific locations of the exciters in the area of the panel, and readily including whatever coincidence frequency or frequencies apply with achieved removal of about 10dB SPL maximum otherwise occurring at extreme angles to the panel surface.

Typical loudspeakers of the large size indicated in Figures 1 and 2 often serve as centre channel loudspeakers, perhaps also viewing screens for so-called home-movie or multi-media installations. Usually frame specifications

allow attachment of the panel 11 to a wall by mountings 23, and may also allow attachment of a cosmetic border to the front of the panel 11. Low frequency performance may be improved by a minimum for spacing of the panel as such from any rear wall, and may be achieved by fixing a layer of acoustically absorbent material, e.g. foamed polyurethane sheet, to the rear of the panel and its normal frame, say to give absorption above 800Hz and a rearward spacing of about 40 mm to about 80 mm.

All of the dimensions marked on Figures 1, 2 and 8 should be treated as no more than wholly exemplary. Some exciters, marked with a cross on Figure 8, are located at optimised locations according to distributed mode reaching, see e.g. WO97/09842.

A four-exciter configuration can be used with all exciters operating on a full-range basis in a series-parallel combination, say to yield a 6 ohm load to a signal supply amplifier. Alternatively, input signal frequencies above the region for cancellation of the effects related to coincidence frequencies could be radiated from the exciters 13 and 15 by connecting a high pass filter across the other exciters, see Figure 7 and capacitor 39. This can produce a higher frequency lift (if required or desired and variable by way of a suitable resistor in series with the capacitor 39) and reduce interference effects at high frequencies that may be audible to a listener walking round the panel. In order to maintain symmetry as mentioned above between the cancellation exciters as to mechanical

action in the cancellation range, the phases of currents flowing in each of the exciters should change as little as possible, and any necessary compensation should be applied, e.g. a 6μF capacitor will result in a 12-degree current phase shift at 2KHz and that can be equated to a separation spacing reduction of 3mm, which can be compensated by a like increase in the separation spacing between the exciter pairs 13,15 and 17,19 in Figure 2 or 8. Using a series resistor with the capacitor 55 can reduce the compensating change of separation.

The additional exciters have little effect on the anechoic, on-axis frequency response, as the majority of the panel does not lie on the lines joining the exciters. Most of the panel surface therefore undergoes the normal bending wave behaviour caused by standard exciter positions. Measuring the echoic response (in room) shows an improvement when the method is used, as reflections do from the walls, ceiling and floor have smoothing additive effect.

Figures 11 and 12 relate to calculations of panel displacement. When a bending wave panel vibrates displacement of the panel occurs related to the bending wave action. Instead of a simple forward-backward motion of the whole panel as occurs with conventional pistonic speakers more complex patterns of displacement occur. Figure 11 shows a calculation of panel displacement using two spaced exciters at 71, 73, and Figure 12 shows as a

comparison panel displacement using only one exciter at 71. Both Figures relate to calculations using energy supplied by the exciters at the coincidence frequency. Both these figures are simplified in that the panel is modelled in one length dimension and one perpendicular dimension. Accordingly, some of the complexity of real two-dimensional panels bending to cause displacement in the third dimension is lost. Nevertheless, the results show the large panel displacement at coincidence seen in Fig.12 using only one exciter being substantially cancelled in the arrangement of Fig.11 with two exciters. In the acoustic domain this effect results in a reduction in the sound pressure level at extreme angles to the panel surface at the coincidence frequency. That is because the large panel displacement couples to air to produce sound at extreme angles, and this coincidence effect (often known as beaming) is reduced.

On axis sound pressure has been calculated for the one and two exciter cases of Figures 11 and 12 and the results are shown in Fig.13. The results for one exciter are shown in the lower solid line and those for two exciters in the upper dotted line. Since two exciters produce double the power, the dotted line is at a sound pressure level of roughly three decibels higher than that of the solid line. The results are calculated for the anechoic case, i.e. they do not take any echoes into account. No peak in the pressure response of the function of frequency is visible with either one or two exciters; this is because the peak at coincidence emits sound at extreme angles to the axis.

Therefore, to show the effect of using two exciters, it is necessary to consider the angular dependence of sound pressure level.

Figure 14 shows the sound pressure level radiated in different directions at a frequency substantially below coincidence at 541.7 Hz. As can be seen, radiation is substantially isotropic at this frequency.

Figure 15 shows the result at coincidence (2039 Hz). The results from only one exciter show very substantial peaks and dips at extreme angles. These peaks and dips are substantially smoothed in the two exciter case.

Figure 16 shows results well above coincidence at 4515 Hz. The cancellation does not occur at this frequency.

An alternative way of presenting these results is to integrate all the sound pressure level over all angles as a function of frequency. Figure 17 shows the result, again with one and two exciters. The peak at coincidence (around 2000 Hz) is significantly larger with one exciter than with two.

These calculated results have been confirmed using measured samples. The test sample is shown in Figures 18 and 19 and is made of 3.5 mm thick aluminium honeycomb 51 with carbon fibre skins 53 and a vinyl cover 55 stuck to the front face with 50gsm thermoplastic scrim. The panel is a rectangular panel measuring 220mm along the short axis 57 by 440mm along the long axis 59. First and second exciters 61,63 are mounted on the panel; they are each 25mm exciters with a reduced mass ring coupling them to the

panel. The first exciter 61 is located at 94mm along the short axis and 195mm along the long axis measured from the nearest corner; the second exciter 63 is mounted 43mm from the first exciter at an angle of 22.5° towards the nearest corner from the direction of the first long axis.

Figure 20 shows the acoustic power measurements with this panel driven with the first exciter 61 and Figure 21 shows the results driving both exciters 61, 63. It should be noted that in both of these Figures the data below 200 Hz should be ignored as it is not accurately captured by the measurement equipment. From a comparison of these graphs it can be seen that the peak at the coincidence frequency (around 3600 Hz) is substantially reduced using two exciters rather than one.

Unlike the larger example of Figures 2 and 8 this panel is sufficiently small in the direction along the short axis (220mm) that coincidence beaming in the direction of this axis is not a significant problem. Accordingly, good results can be obtained using only two exciters.

Figure 22 shows a detail of an alternative arrangement in which first 13 and second 15 exciters are arranged close together and the second exciters is connected in anti phase to the first exciter through a bandpass circuit 81, and leads 83. As mentioned above, this arrangement may be used with spacings between the exciters other than half-wavelength of the feature.

CLAIMS

1. A bending wave loudspeaker comprising

a panel (11) capable of supporting bending waves,

a first exciter (13) mounted on the panel for exciting bending waves in the panels to produce an acoustic output, wherein the acoustic output response of the panel(11) driven by said first exciter (13) has an feature at a known frequency, and

a second exciter (15) mounted on the panel for exciting bending waves in the panel (11) to produce an acoustic output, wherein the position, spacing, orientation, phase, filter characteristics and/or gain of the second exciter (15) relative to the first are arranged such that when the first and second exciters (13, 15) are commonly driven the feature is smoothed.

2. A loudspeaker according to claim 1 wherein the known frequency is the coincidence frequency.

3. A loudspeaker according to claim 1 or 2 wherein the second exciter (15) is arranged spaced away from the first exciter (13) on the panel (11) at a distance substantially equal to one half of the wave length of bending waves in the panel at the known frequency.

4. A loudspeaker according to any preceding claim wherein the first and second exciters (13, 15) are connected in phase so that the bending waves emitted by the exciters are in phase.

5. A loudspeaker according to claim 4 wherein the first

and second exciters are connected between common terminals.

6. A loudspeaker according to any preceding claim wherein the panel has first (35) and second axes (37), and the second exciter (15) is spaced away from the first exciter (13) along the first axis (35) to smooth the coincidence frequency feature associated with the bending waves along the first axis (35).

7. A loudspeaker according to claim 6 wherein a third exciter (17) is provided spaced away from the first exciter (13) along the second axis (37) at a distance substantially equal to one half the wave length of the bending waves at the coincidence frequency along the second axis (37).

8. A loudspeaker according to claim 7 wherein a fourth exciter (19) is provided so that the first (13), second (15), third (17) and fourth (19) exciters define a rectangle on the surface of the panel (11).

9. A loudspeaker according to claim 1 or 2 wherein the second exciter (15) is located close to the first exciter (13) and connected in anti-phase with it.

10. A loudspeaker according to any preceding claim wherein a filter is provided in association with one of the first and second exciters to selectively pass frequencies in a predetermined frequency band around the known frequency through the associated exciter.

11. A loudspeaker according to claim 10 wherein the filter is bandpass filter (81) in series with the associated exciter.

12. A loudspeaker according to any preceding claim further

comprising a higher frequency exciter (21) for exciting frequencies above a predetermined cutoff frequency, and a crossover circuit (20) for feeding the higher frequency exciter (21) with the frequencies above the cutoff and the other exciters (13,15,17,19) with the frequencies below the cutoff.

13. A bending wave loudspeaker, comprising

a panel (11) capable of supporting bending waves,

first and second exciters (13,15)mounted on the panel (11) for exciting bending waves in the panel to produce an acoustic output, wherein

the first and second exciters (13,15) are spaced apart by a distance of one half wave length at a predetermined frequency, so that when the first and second exciters are commonly driven the acoustic output of the panel is affected at the predetermined frequency.

14. A loudspeaker according to claim 13 wherein the first and second exciters (13,15) are connected in anti-phase to enhance the acoustic output at the predetermined frequency.

15. A loudspeaker according to claim 13 wherein the first and second exciters (13,15) are connected in phase to reduce the acoustic output at the predetermined frequency.

16. A loudspeaker according to claim 15 wherein the known frequency is the coincidence frequency.

17. A loudspeaker according to claim 15 or 16 wherein the first and second exciters (13, 15) are connected in phase so that the bending waves emitted by the exciters are in phase.

18. A loudspeaker according to claim 17 wherein the first and second exciters are connected between common terminals.

19. A loudspeaker according to any of claims 15 to 18 wherein the panel has first (35) and second axes (37), and the second exciter (15) is spaced away from the first exciter (13) along the first axis (35) to smooth the coincidence frequency feature associated with the bending waves along the first axis (35).

20. A loudspeaker according to claim 19 wherein a third exciter (17) is provided spaced away from the first exciter (13) along the second axis (37) at a distance substantially equal to one half the wave length of the bending waves at the coincidence frequency associated with the second axis (37).

21. A loudspeaker according to claim 20 wherein a fourth exciter (19) is provided so that the first (13), second (15), third (17) and fourth (19) exciters define a rectangle on the surface of the panel (11).

22. A loudspeaker according to any of claims 13 to 21 further comprising a filter (81) in association with one of the first and second exciters to selectively pass frequencies in a predetermined frequency range around the predetermined frequency.

23. A loudspeaker according to any of claims 13 to 22 further comprising a higher frequency exciter (21) for exciting frequencies above a predetermined cutoff frequency, and a crossover circuit (20) for feeding the higher frequency exciter (21) with the frequencies above

the cutoff and the other exciters (13,15,17,19) with the frequencies below the cutoff.

24. A method of suppressing an feature in a frequency response of a bending wave loudspeaker having a panel (11) capable of supporting bending waves, and a first exciter (13) mounted on the panel, including

determining a frequency at which the response of the first exciter on the panel has a feature,

providing a second exciter (15) on the panel arranged such that when the first and second exciters (13,15) are commonly driven the feature is smoothed.

25. A method according to claim 24 wherein the second exciter is provided on the panel at one half of the wavelength of bending waves in the panel at the known frequency.

26. A method according to claim 24 or 25 wherein the step of determining the frequency determines the coincidence frequency associated with a predetermined direction.

Figure 1.

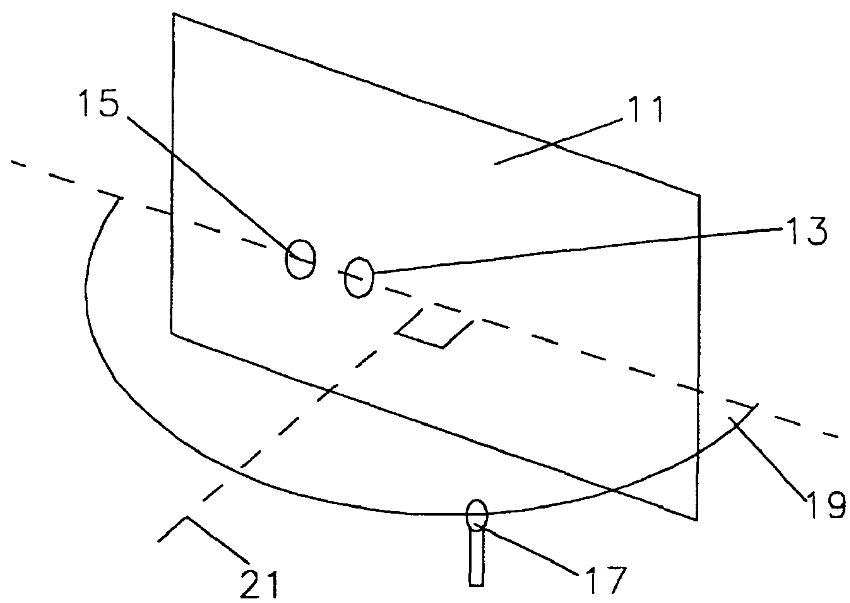


Figure 2

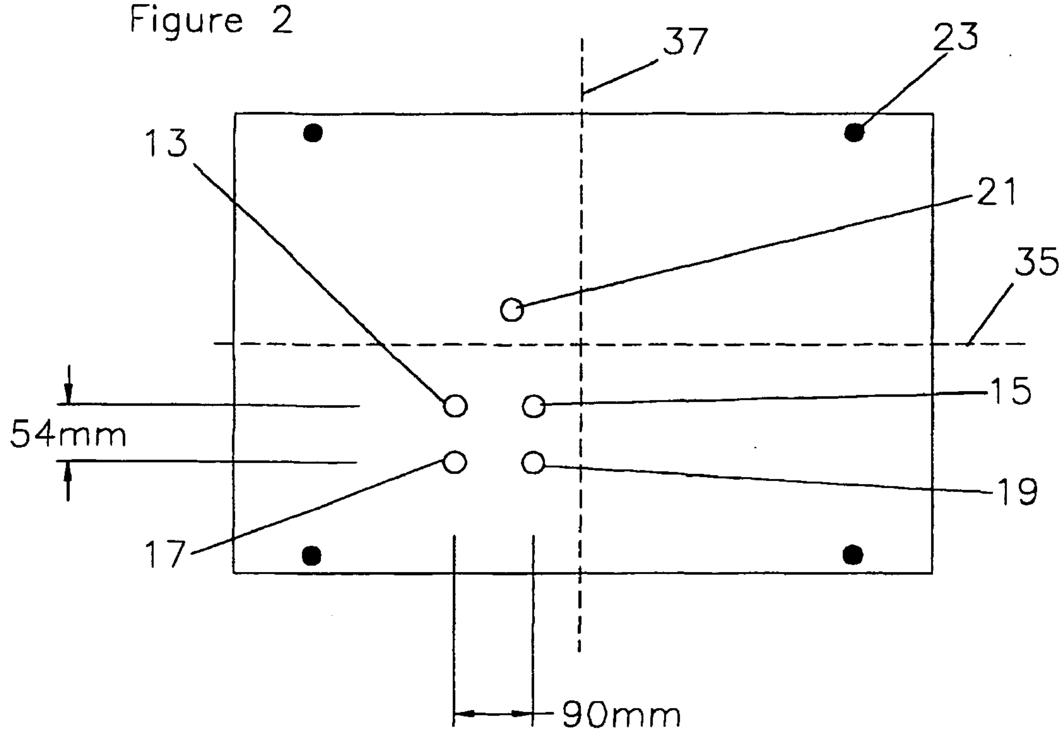


Figure 3

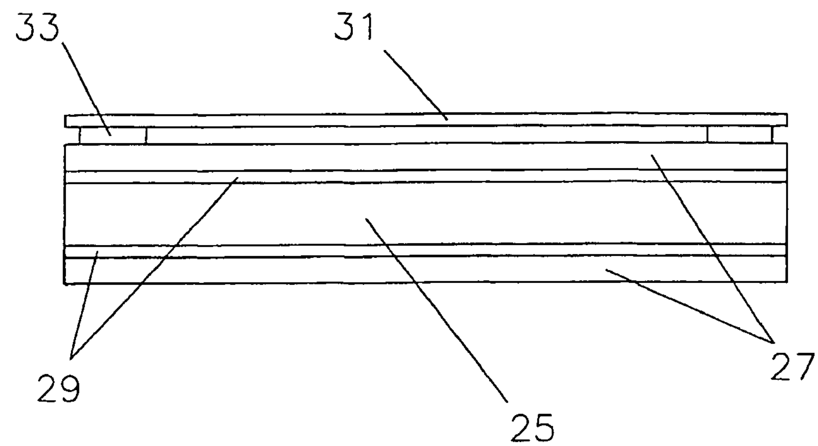


Figure 7

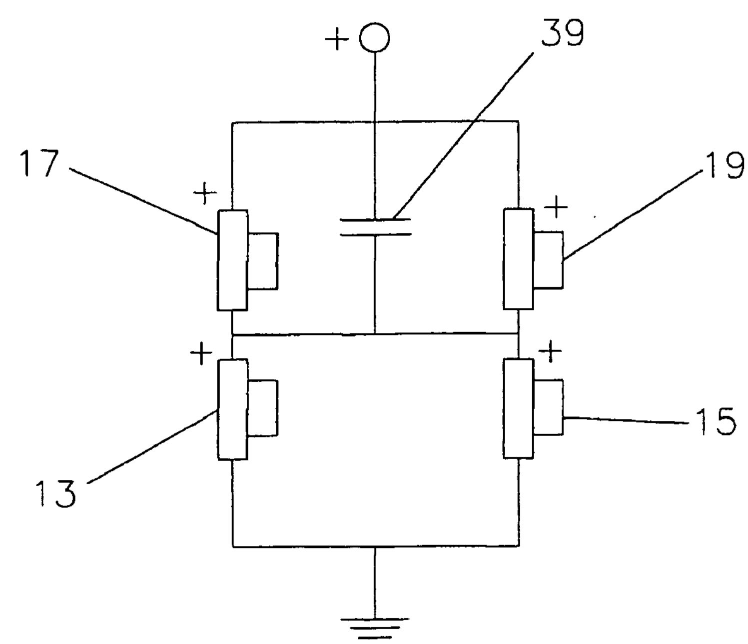


Figure4

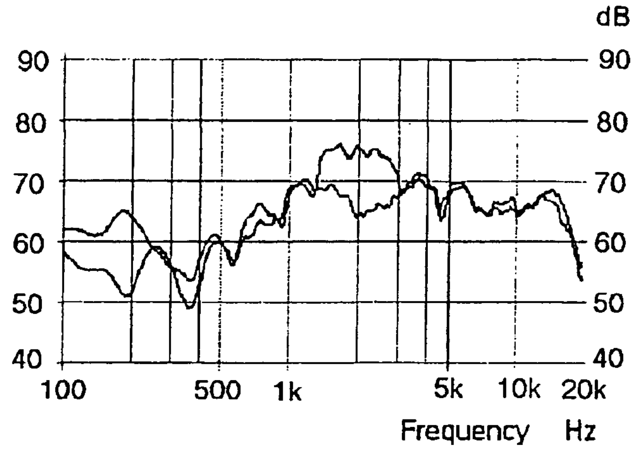


Figure 5

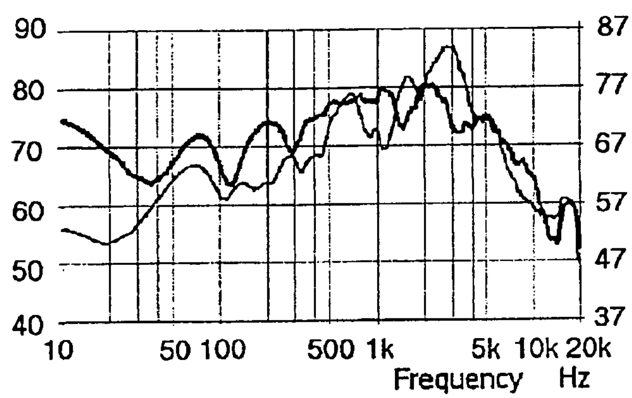


Figure 22

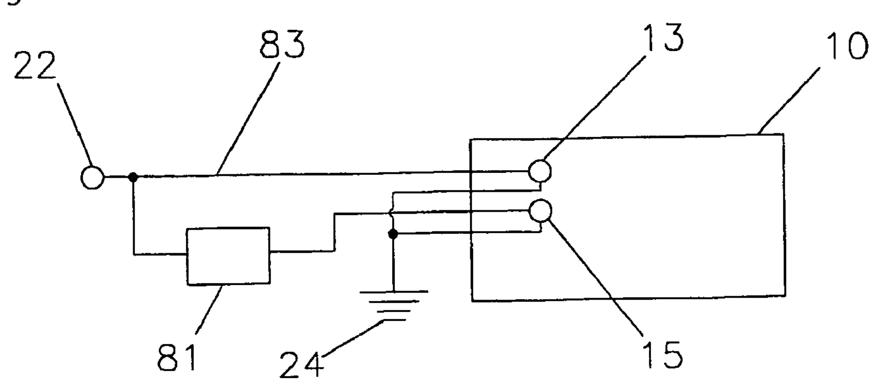
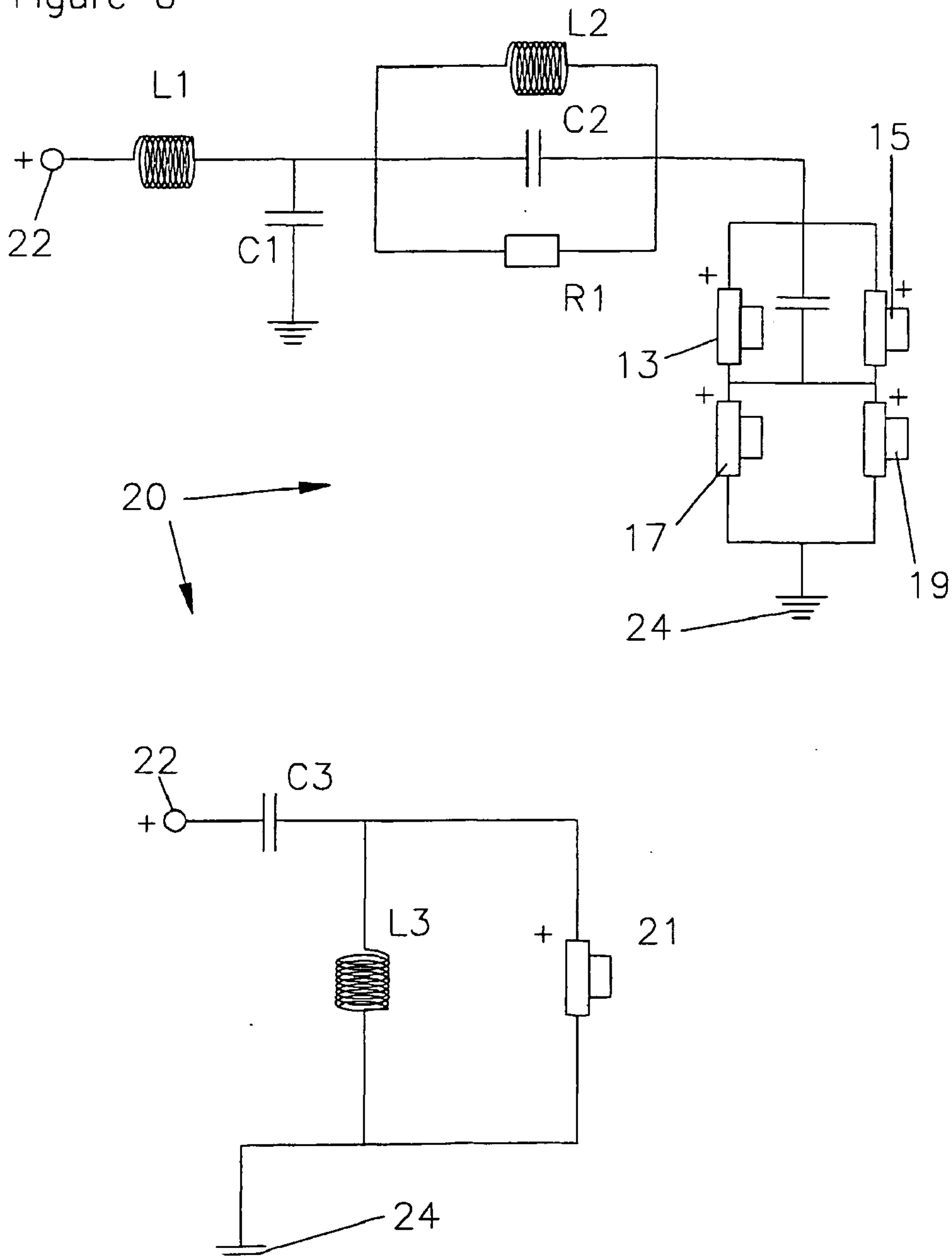
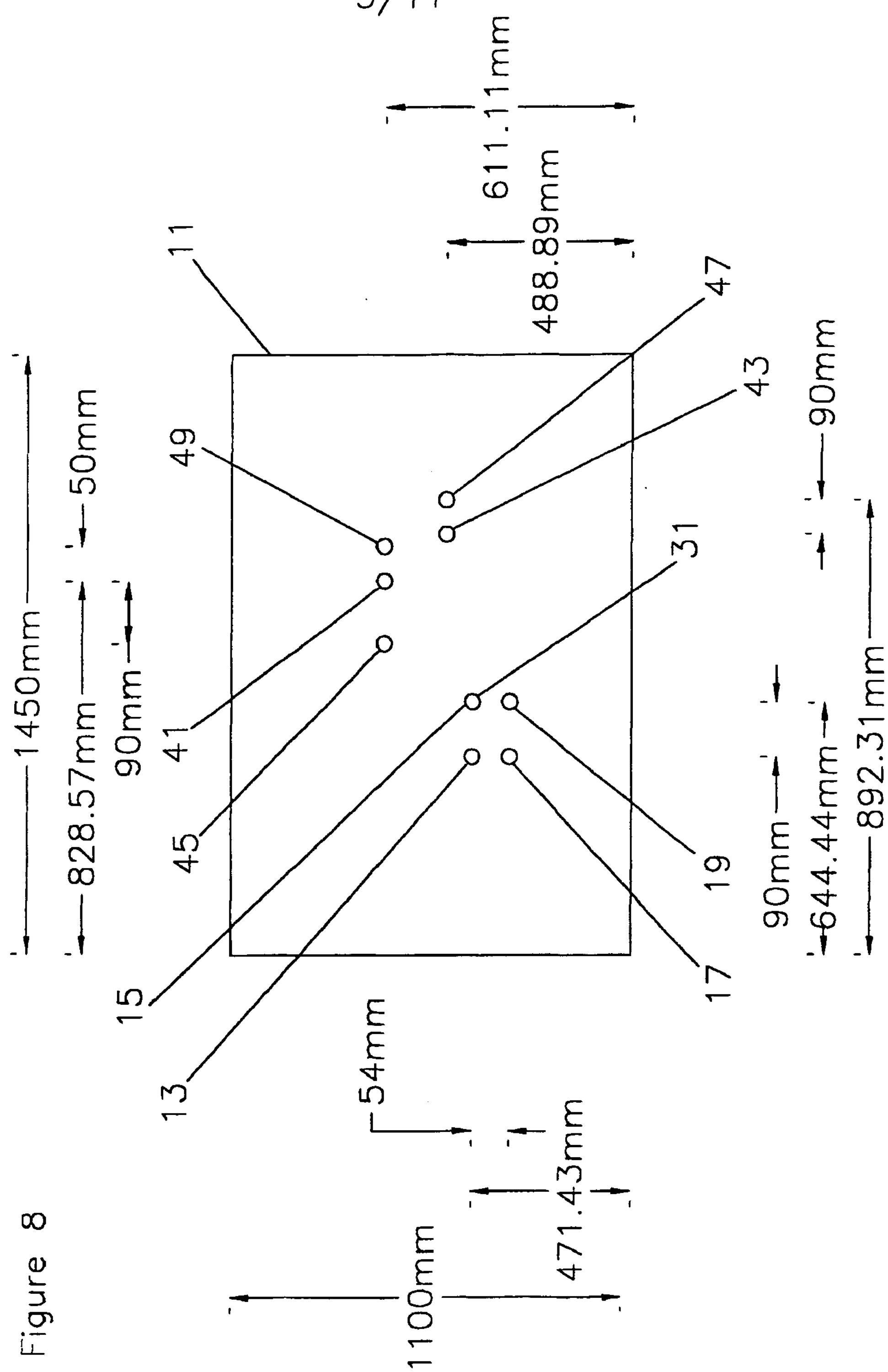


Figure 6

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488.89mm
11
47
43
49
50mm
90mm
1450mm
828.57mm
90mm
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15
13
19
17
90mm
644.44mm
892.31mm
54mm
471.43mm
1100mm

Figure 8

Figure 9

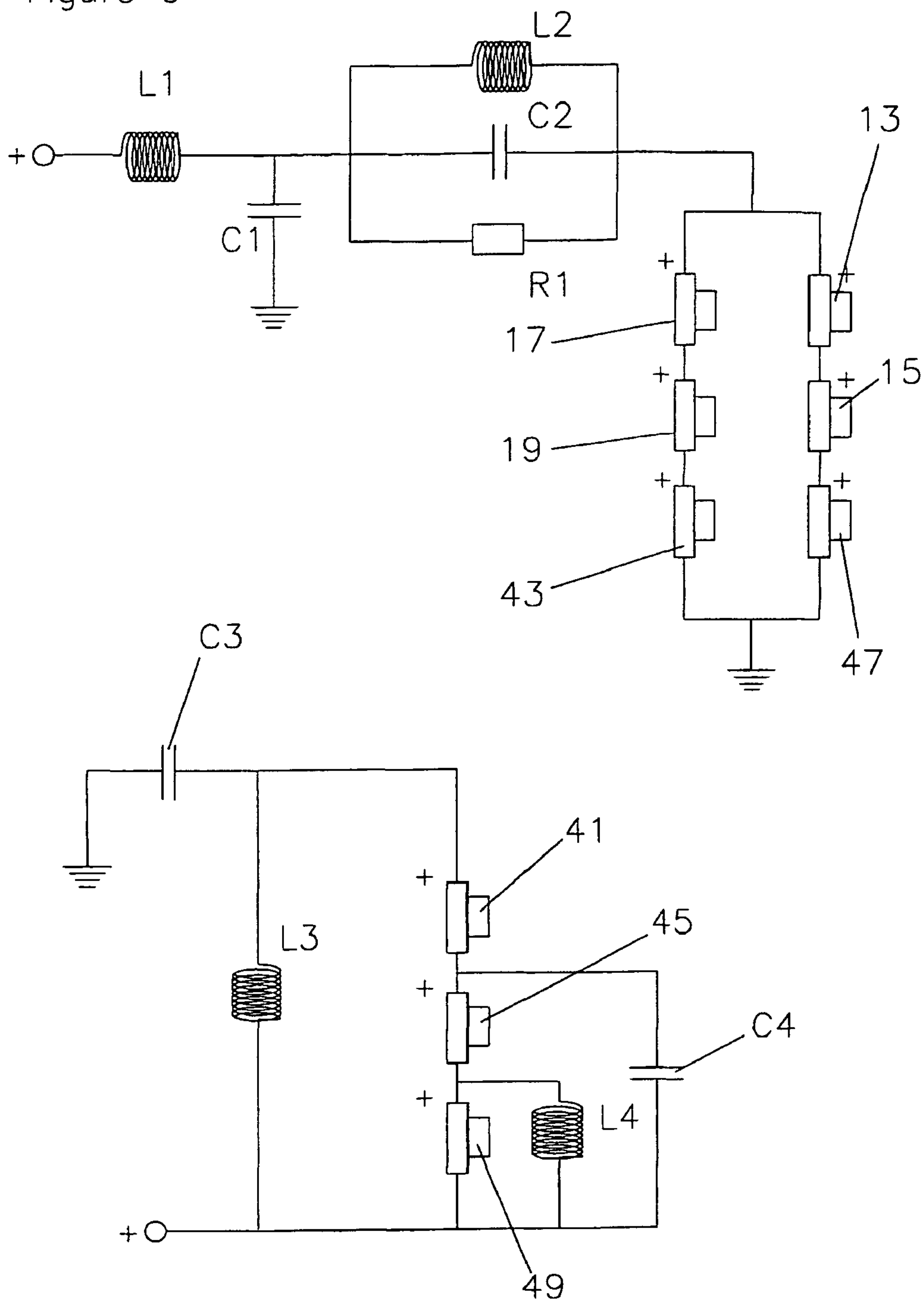


Figure 10

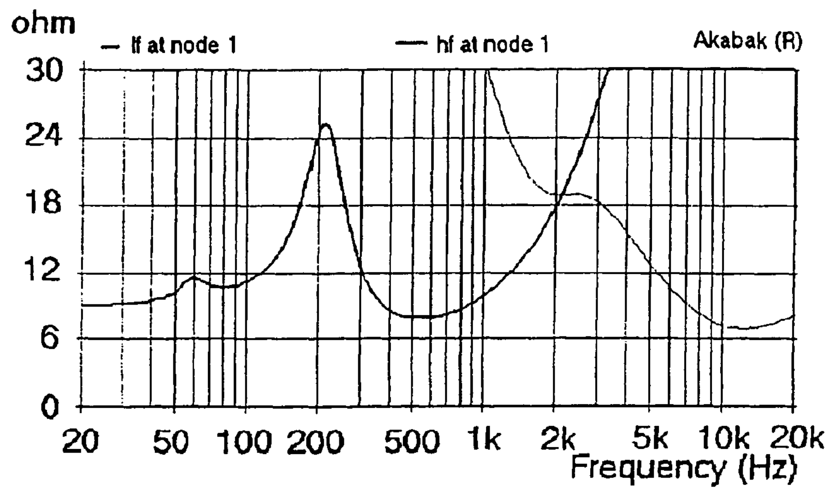


Figure 11

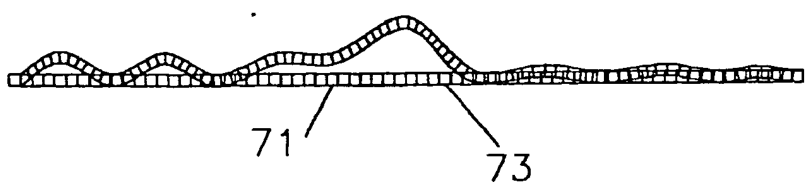


Figure 12

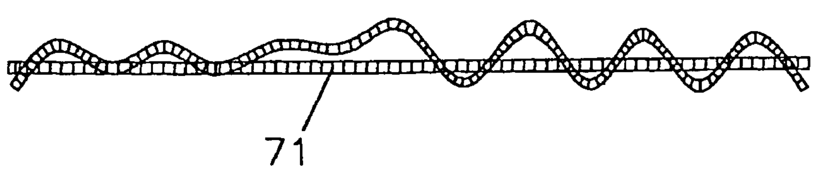
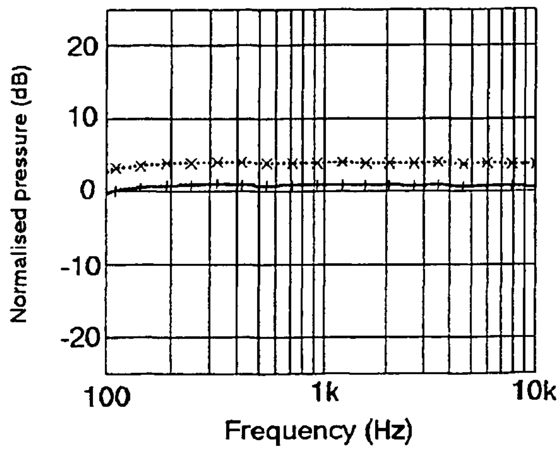


Fig. 13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10
0
-10
-20
Normalised pressure (dB)
100
1k
10k
Frequency (Hz)

Fig. 14

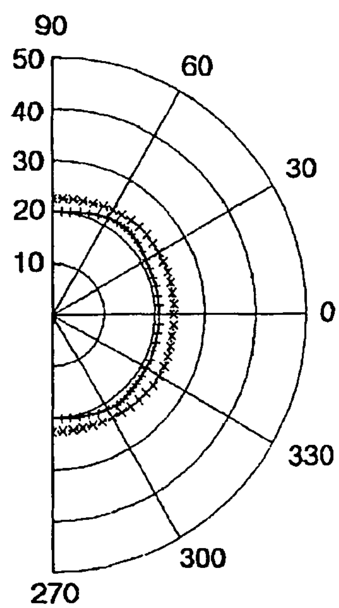
90
60
30
0
330
300
270
50
40
30
20
10

Fig. 15

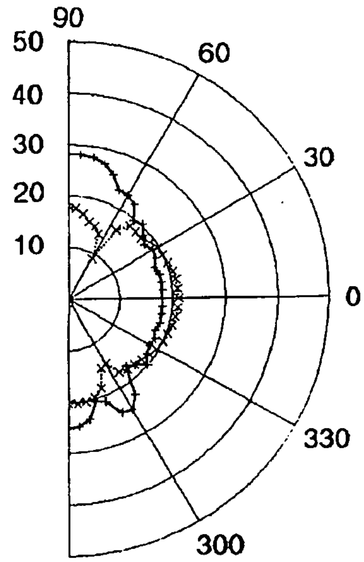

Fig. 16

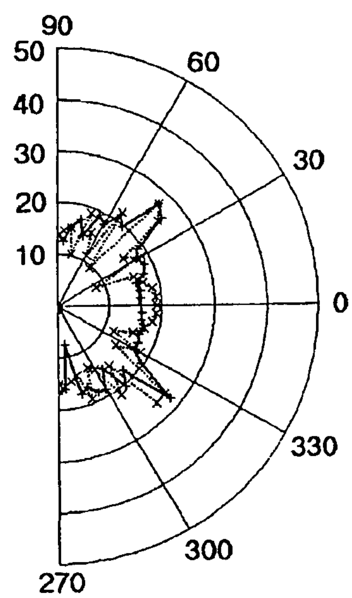

Fig. 17

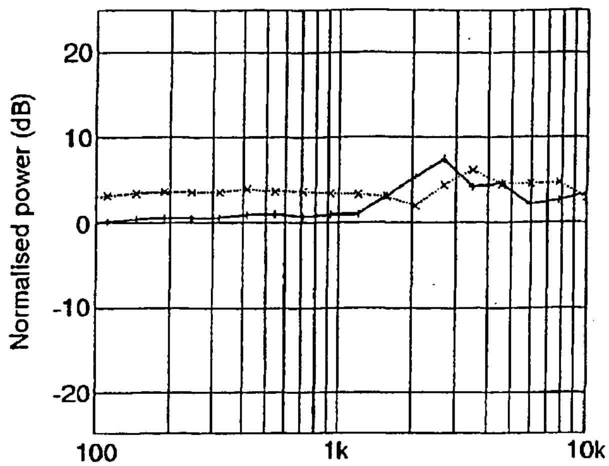

Fig. 20

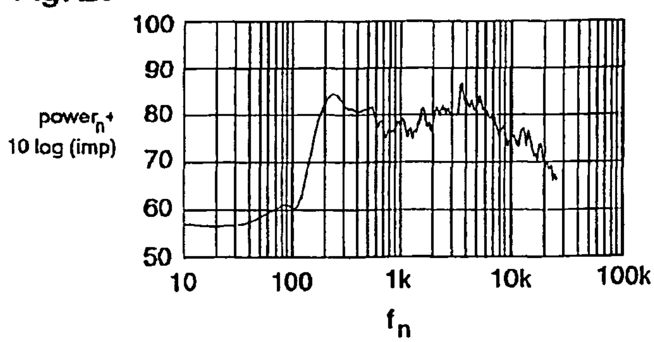

Fig. 21

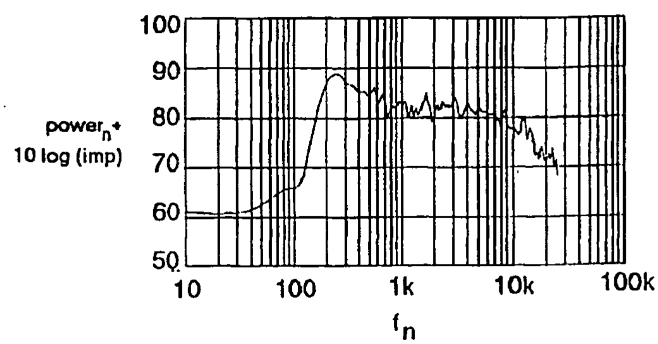

Figure 18

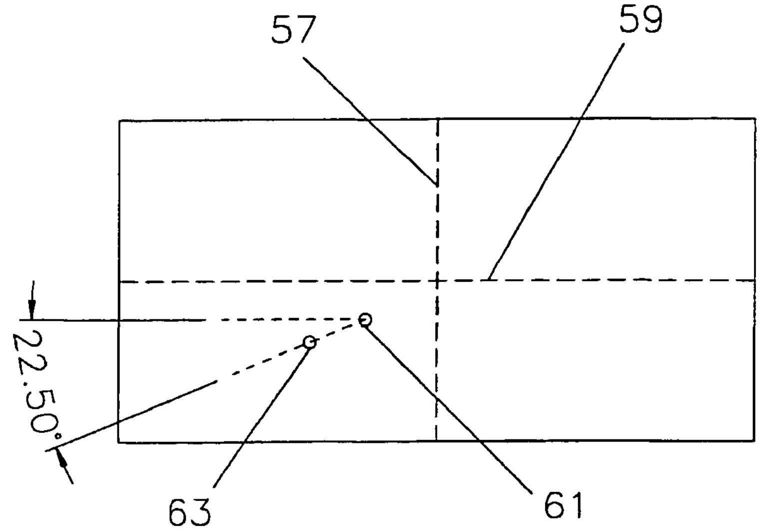

Figure 19